United States Department of the Interior

U.S. GEOLOGICAL SURVEY
Caribbean-Florida Water Science Center
4446 Pet Ln Suite #108
Lutz, FL 33559

March 28, 2023

Gregoiy Mount
Assistant Chief Resilience Officer
Broward County Resilient Envionrnent Department
115 S. Andrews **Ave,** Room 329-L
Fort Lauderdale, FL 33301

Dear Mr. Mount:

Attached is our standard joint-funding agreement for the project, "Evaluation of Changes to the Salinity Distribution within the Surficial Aquifer under Projected Future Hydrologic Conditions, Broward County, Florida", during the period April 1, 2023 through March 31, 2026 in the amount of $524,616 from your agency. U.S. Geological Survey contributions for this agreement are $524,616 for a combined total of$1,049,232. Please sign and return original to Margaret A. Fineagan at email address mfineagan@usgs .gov.

Federal law requires that we have a signed agreement before we start or continue work. Please return the signed agreement by **April 1, 2023.** If, for any reason, the agreement cannot be signed and returned by the date shown above, please contact John Stamm by phone number 813-695-7987 or email jstamm@usgs.gov to make alternative arrangements.

This is a fixed cost agreement to be billed quarterly via Down Payment Request (automated Form DI-1040). Please allow 30-days from the end of the billing period for issuance of the bill. If you experience any problems with your invoice(s), please contact Margaret Fineagan at phone number (813) 498-5009 or email at mfineagan@usgs.gov.

The results of all work performed under this agreement will be available for publication by the U.S. Geological Survey. We look forward to continuing this and future cooperative efforts in these mutually beneficial water resources studies.

Sincerely,

Dorothy Sifuentes

Dorothy F. Sifuentes, PhD
Acting Center Director
USGS Caribbean-Florida Water Science Center

Form 9-1366
(May 2018)

U.S. Department of the Interior
U.S. Geological Survey
Joint Funding Agreement
FOR
Water Resource Investigations

Customer#: 6000001225
Agreement#: 23MCJFA0110
Project#: MCDOE2H
TIN#: 59-60000531

Fixed Cost Agreement **YES[X** I NO(I

THIS AGREEMENT is entered into as of the Apr 1, 2023, by the U.S. GEOLOGICAL SURVEY, Caribbean-Florida Water Science Center, UNITED STATES DEPARTMENT OF THE INTERIOR, party of the first part, and **BROWARD COUNTY** on behatt of its **RESILIENT ENVIRONMENT DEPARTMENT (BCRED)** party of the second part.

1. The parties hereto agree that subject to the availability of appropriations and in accordance with their respective authorities lhere shall be maintained in cooperation a project, "Evaluation of Changes to the Salinity Distribution within the Surficial Aquifer under Projected Future Hydrologic Conditions, Broward County, Florida' (per attachment), herein called the program. The USGS legal authority is 43 USC 36C; 43 USC 50, and 43 USC 50b.

2. The following amounts shall be contributed to cover all of the cost of the necessary field and analytical work directly related to this program. 2(b) include In-Kjnd-Services in the amount of $0.00

(a) $524,616.00 by the party of the first part d:uring the period April 1, 2023 to March 31, 2026

(b) $524,616.00 by the party of the second part during the period April 1, 2023 to March 31, 2026

(c) Contributions are provided by the party of the firs! part through other USGS regional or national programs, in the amount *ot* $0.00

(d) Additional or reduced amounts by each party during the above period or succeeding periods as may be detenmined by mutual agreement and set forth in an exchange of letters between the parties.

(e) The performance period may be changed by mutual agreement and set forth in an exchange of letters between the parties.

3. The costs of this program may be paid by either party in conformity with the laws and regulations respectively governing each party.

4. The field and analytical wor1< pertaining to this program shall be under the direction of or subject to periodic review by an authorized represenlative of the party of the first part

5. The areas to be included in the program shall be determined by mutual agreement between the parties hereto or their authorized representatives. The methods employed in the field and office shall be those adopted by the party of the first part to insure the required standards of accuracy subject to modification by mutual agreement.

6. During the course of this program, all field and analytical wotl< of either party pertaining to this program shall be open to the inspection of the other party, and tt the work is not being carried on in a mutually satisfactory manner, either party may terminate this agreement upon 60 days written notice to the other party.

7. The original records resulting from this program will be depostted in the office of origin of those records. Upon reques copies of the original records will be provided to the office of the other party.

8. The maps, records or reports resulting from this program shall be made available to the public as promptly as possible. The maps, records or reports normally will be published by the party of the first part. However, the party of the second part reserves the right to publish the results of this program, and if already published by the party of the first part shall, upon request, be furnished by the party of the first part, at cost, impressions suttable for purposes of reproduction similar to that for which the original copy was prepared. The maps, records or reports pubfished by either party shall contain a statement of the cooperative relations between the parties. The Parties acknowledge that scientific information and dala developed as a result of the Scope of Woll< (SOW) are sl.bject to applicable USGS review, approval, and release requirements, which are available on the USGS Fundamental Science Practices website {https:/twww.usgs.govtabout/organizatioo{scieoce-supporVscience-0uality-ant1-inteority/fundamentat-science-P@ctices).

Form 9-1366
(May 2018)

U.S. Department of the Interior
U.S. Geological Survey
Joint Funding Agreement
FOR
Water Resource Investigations

Customer #: 6000001225
Agreement #: 23MCJFA0110
Project #: MC00E2H
TIN#: 59-60000531

9. Billing for this agreement will be rendered **quarterly.** Invoices not paid within 60 days from the billing date will bear Interest, Penalties, and Administrative cost at the annual rate pursuant the Debt Collection Act of 1982, (codified at 31 U.S.C. § 3717) established by the U.S. Treasury.

USGS Technical Point of Contact

Name:	Jeremy Decker Hydrologist
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Telephone:	813-498-5030
Fax:	813-498-5002
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Customer Technical Point of Contact

Name:	Gregory Mount Assistant Chief Resilience Officer
Address:	115 S Andrews Ave, Room 329-L Fort Lauderdale, FL 33301
Telephone:	954-519-0356
Fax:	
Email:	gmount@broward.org

USGS Billing Point of Contact

Name:	Margaret Fineagan Budget Analyst
Address:	4446 Pet Lane Lutz, FL 33559
Telephone:	(813) 498-5009
Fax:	
Email:	mfineagan@usgs.gov

Customer Billing Point of Contact

Name:	Gregory Mount Assistant Chief Resilience Officer
Address:	115 S Andrews Ave, Room 329-L Fort Lauderdale, FL 33301
Telephone:	954-519-0356
Fax:	
Email:	gmount@broward.org

U.S. Geological Survey
United States
Department of Interior

Signature

DOROTHY SIFUENTES Digitally signed by DOROTHY SIFUENTES Date: 2023.03.28 09:33:53 -04'00'

By_____ **Date: 02/22/2023**

Name: Dorothy F. Sifuentes, PhD

Title: Acting Director, Caribbean-Florida Water Science Center

Broward County

Signatures

By_____ **Date:** ___ _

Name:

Title: County Mayor

By_____ **Date:** ___ _

Name:

Title: County Administrator

By_____ **Date:** ___ _

Name:

Title:

Reviewed and approved as to form by:

Deanna Kalil Digitally signed by Deanna Kalil Date: 2023.04.04 15:06:33 -04'00'

Deanna Kalil
Assistant County Attorney

MAITE AZCOITIA Digitally signed by MAITE AZCOITIA Date: 2023.04.04 17:38:18 -04'00'

Maite Azcoitia
Deputy County Attroney

ProposalNumber:20220628091316

Title: Evaluation of Changes to the Salinity Distribution within the Surficial Aquifer under Projected Future Hydrologic Conditions, Broward County, Florida

Cooperator: Broward County Resilient Environment Department

1. Executive Summary:

This proposal describes a proposed cooperative study between the U.S. Geological Survey and Broward County, Florida, on behalf of its Natural Resources Division. The primary objective of this study would be to evaluate the changes to the spatial distribution of salinity within the surficial aquifer for the urbanized areas of Broward County resulting from projected future hydrologic conditions. A variable density groundwater flow and transport model will be developed based on existing models and will incorporate improvements to input data, simulation tools, and parameter estimation techniques.

Future scenarios will be developed using projected sea-level estimates and changes to climate. Model output (e.g., water levels, system flows, and salinity distribution) will be used to evaluate the groundwater system's response to projected future hydrologic conditions. Simulations may incorporate possible adaptation or mitigation strategies such as reallocation of well-field pumping rates or changes to the surface-water controls. A USGS report documenting the development of the flow and transport model and study results will be produced. Additionally, the flow and transport model and model archive will be released to the cooperator and the public as a USGS Data Release.

2. Background and Problem Statement:

Saltwater intrusion into the coastal part of the surficial aquifer of southeast Florida is a major concern for water-supply managers in Broward County, Florida. The general west-to-east decrease in the height of the potentiometric surface causes flow of fresh groundwater eastward and towards the saline groundwater that intrudes along the coastline. The result is a dynamic mixing zone that forms the interface between the two fluids, which is often called the saltwater front. The location of the saltwater front and the width of this mixing zone is heavily influenced by the local hydrology and responds to changes to the hydrologic conditions. Increases in mean sea level would likely lead to decreased west-to-east groundwater level gradients resulting in a reduced seaward fresh-groundwater flux and westward intrusion of the saltwater front. Increases in coastal wellfield pumping or decreases in groundwater recharge (e.g., dry season, periods of drought) can also lead to saltwater intrusion. Conversely, decreases in coastal wellfield pumping and increases in groundwater recharge (e.g., wet season, wet years) can result in the seaward movement of the saltwater front. Saltwater intrusion into the coastal wellfields poses a threat to the fresh drinking water supplies in coastal areas. A variable density, numerical groundwater model capable of simulating the three-dimensional distribution of salinity within the surficial aquifer could be used to simulate the encroachment of the saltwater front further into the county under various projections of future hydrologic conditions.

The U.S. Geological Survey has developed three variable-density numerical models for Broward County in recent years. Dausman and Langevin (2005) developed a variable density model of a hypothetical area patterned after west-central Broward County using the SEAWAT (Langevin and others, 2008) modeling code. The study focused on the causes of saltwater intrusion and was used to determine the feasibility of developing a calibrated saltwater intrusion model for the coastal well fields within the county. The model was able to simulate long-term saltwater intrusion patterns and led to the development of two additional studies. Langevin and Zygnerski (2013) developed a SEAWAT model for the northern portion of Broward County to evaluate the sensitivity of well-field water quality to sea-level rise and changes to well-field pumping rates (fig. 1). The "northern model" was calibrated using Parameter ESTimation (PEST) software (Doherty, 2010) and sea-level rise was simulated using four different rates over a 100-year period. Hughes and others (2016) used the techniques from these previous two models to develop a saltwater-intrusion m<>del for the central and southern parts of Broward County. The "central/southern model" was calibrated using PEST and simulated historical conditions from 1950 to 2012 (fig. 2). The model was used to evaluate the sensitivity of the salinity distribution to sea-level rise and changes to well-field pumping rates. Since the release of the northern and central/southern saltwater intrusion models, Broward County has worked to combine the model inputs into one "merged model" encompassing all the urban areas within the county. The county has also worked to extend the historical simulation period and further refine the model input datasets.

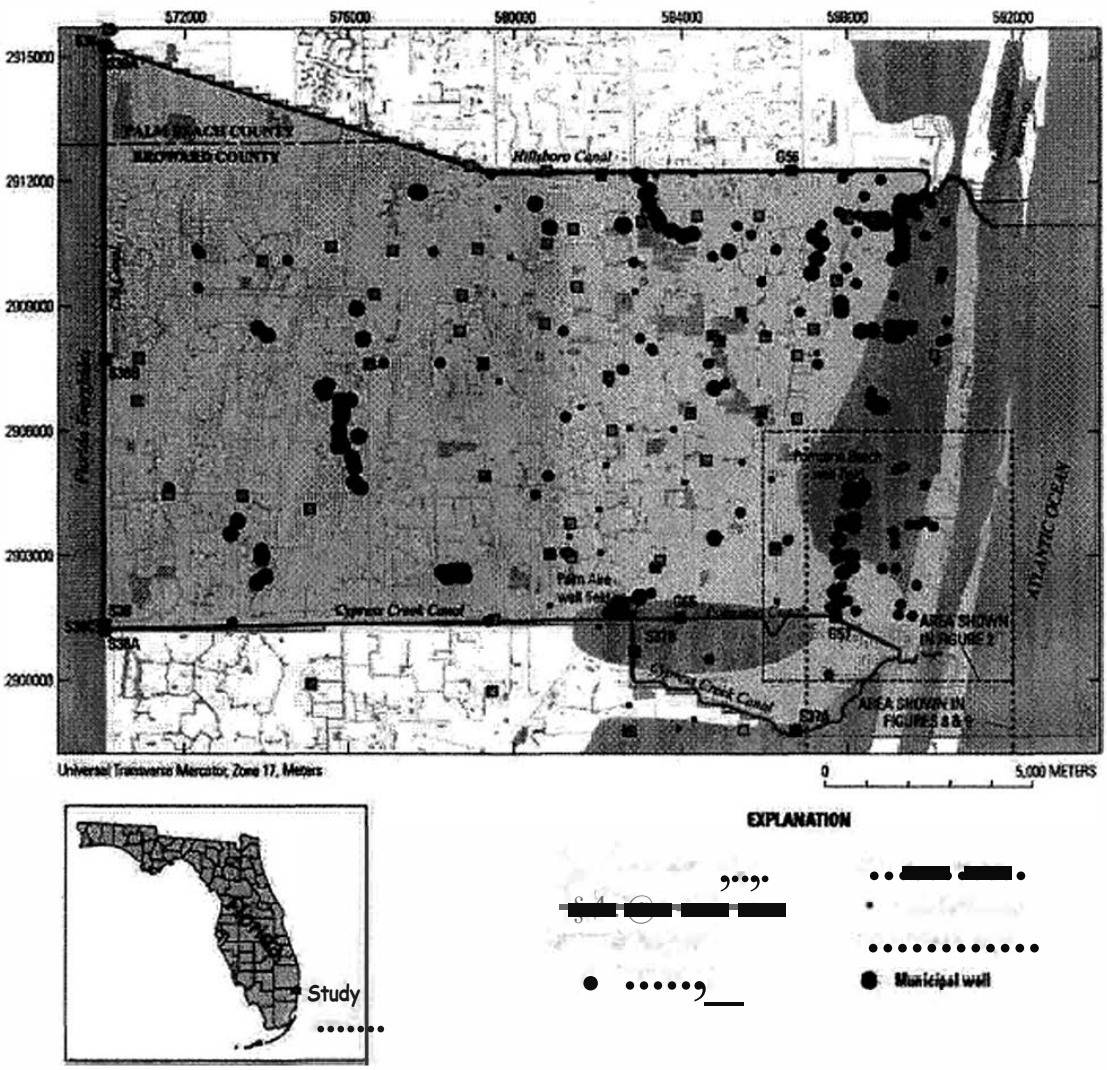

Figure I. Map of study area showing active model domain, surface-water control structures, municipal wells, and surface water gauges used for the variable-density saltwater intrusion model developed for northern Broward County (Langevin and Zygnersld, 2013).

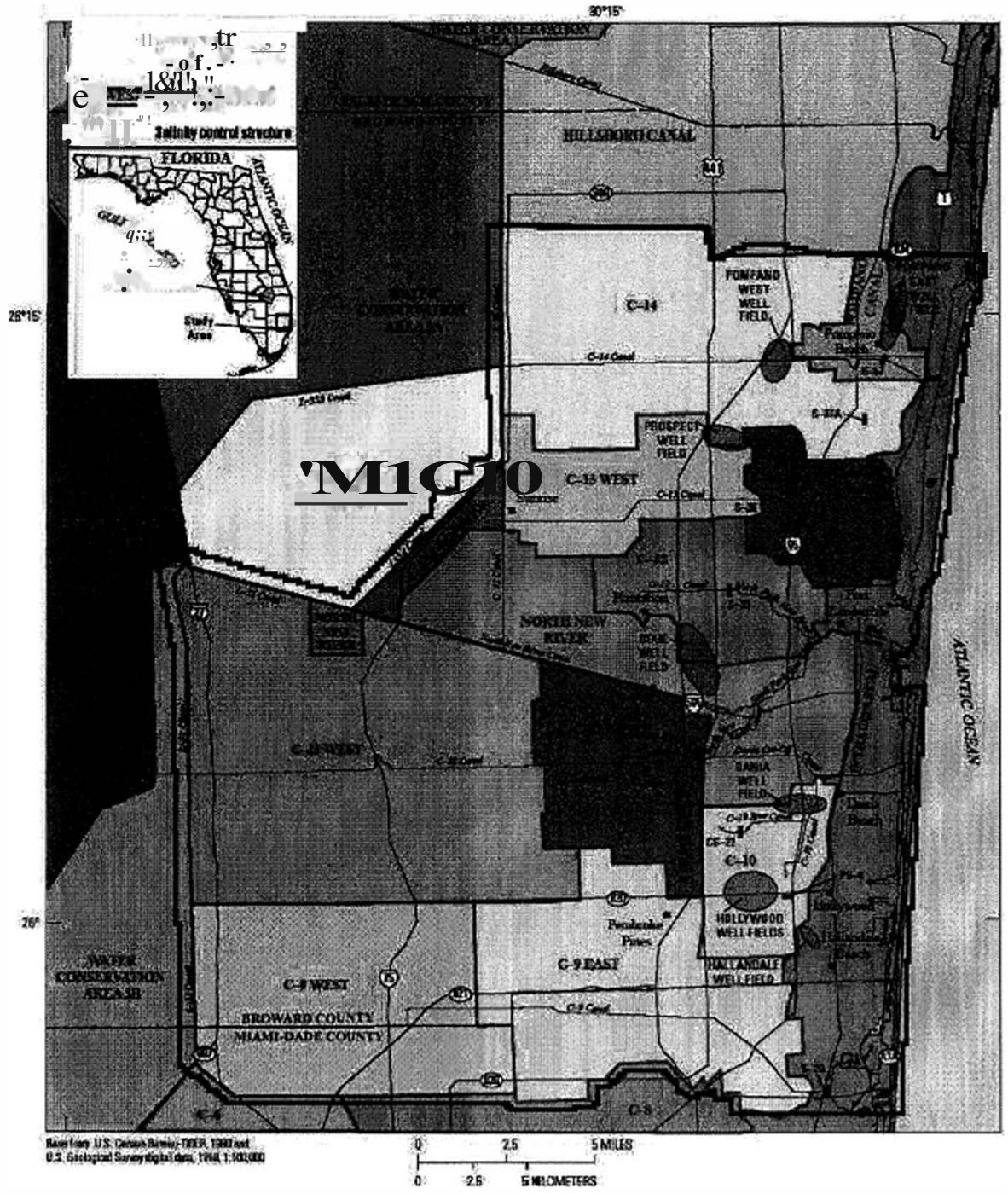

Figure 2. Map of the study area showing the active model domain, surface-water control structures, and municipal well fields used for the variable-density saltwater intrusion model developed for central/southern Broward County (Hughes and others, 2016).

Related modeling efforts include two studies within Broward County to evaluate the likelihood for increased inundation under various future mean sea levels and a study conducted in neighboring Miami-Dade County to simulate the salinity intrusion under future sea level and well-field pumping scenarios. The studies conducted in Broward County (referred to as the "inundation models") used the calibrated aquifer parameters from the central/southern saltwater intrusion model but were not variable density and did not include solute transport (Decker and others, 2018; Decker, 2021). The inundation models were focused on the simulation of the surface-water control structures under future projections of sea level and the effects on groundwater. The study conducted in Miami-Dade also did not include solute transport but did use the SeaWater Intrusion **(SWI)** package in MODFLOW to simulate the saltwater interface and its movement due to changes in sea level and pumping rates (Hughes and White, 2014). Additionally, the USGS developed a solute transport model known as BISECT that covered the southern end of Florida, which included Miami-Dade County as well as Everglades National Park (Swain and others, 2019). The BISECT model was used to study the effects of sea-level increases as well as changes in other parameters and forcings on the distribution salinity within the surface-water and groundwater systems.

The next step in the evolution of the variable density models within Broward County is to further develop the merged model by incorporati$_{n\,g}$ improved input datasets, expanding the historical simulation period, improve the calibration of the model, and test future scenarios with more recent sea-level and climate projections.

3. Objectives and Scope:

The primary objective of the proposed study is to develop a tool to simulate the distribution of salinity within the surficial aquifer for the urban areas of Broward County under historical and/or projected conditions and to assess the projected changes to the saltwater front due to expected or proposed changes to the hydrologic conditions (e.g., sea level, wellfield pumping rates, recharge). The approximate active model domain is represented by the combined northern and central/southern models (figs. 1 & 2) which constitute the merged model that Broward County and the USGS have developed. The project's primary objective can be further divided into five specific objectives:

1. Accurately simulate the historical (approximately 50 year) saltwater distribution and the patterns of change detected within the salinity data observed at the monitoring stations throughout the county.
2. Simulate the potential changes to salinity distribution in the coastal areas due to projected increases in mean sea level (approximately 50 year).
3. Evaluate the influence of coastal well-field pumping on the location and advancement of the salw ater front for historical and future sea level simulations.
4. Evaluate the influence of aquifer recharge estimates (that acknowledge climate model-simulated changes in precipitation) on the salinity distribution within the surficial aquifer under projected future mean sea levels.
5. Develop a hydrologic budget for the modeling domain that accounts for recharge, evapotranspiration, surface-water/groundwater exchange, changes in aquifer storage, and groundwater flux to and from the surficial aquifer along the boundaries.

4. Relevance and Benefits:

The results from the proposed study will help infonn Broward County managers on the current, historical, and projected future spatial distributions of salinity within the surficial aquifer and help identify the primary influences on the advancement of the saltwater front. The variable density numerical model developed during the study will provide the county with a tool capable of simulating projected future conditions and evaluate the effects of various changes to the hydrologic conditions on the salinity distribution. Additionally, during the project it would be desirable to communicate the importance and improve the understanding of the effects of future sea level and water use on salinity intrusion within the region to a broader audience. These beneficial outreach activities could include presentations at local colleges and universities, regional utilities, or local chapter meetings of environmental gi-oups.

This study aligns with the goals, objectives, and actions outlined in USGS circular 1383-G (Evenson and others, 2013) by providing/aiding in the (I) advancement of the understanding of processes that determine water availability and effects from human interactions (Goal 2, Objective 4, Strategic Action 12); (2) development and application of models to predict the potential effects of changes in population, land-use, climate, and management practices upon future water availability considering human and ecological needs (Goal 3, Objective I, Strategic Action 14, JS, 16, 17); and (3) identifying the current and future threats to communities from water-related hazards (Goal 4, Objective I, Strategic Actions 19, 20). The proposed project also aligns with the Caribbean-Florida Water Science Center Strategic Science Plan (Stamm and others, 2017) by evaluating water availability, water quality, and the risk of further saltwater intrusion in response to increased sea level and providing tools to assess the uncertainty of future conditions and the effect on the hydrologic system.

5. Approach

To achieve the projects objectives, a three-dimensional, variable-density groundwater flow and transport model will be further developed from existing groundwater models and will incorporate expanded input datasets, new modeling tools, and will undergo additional parameter estimation with the objective of improving model fit to observed trends. The proposed model will build on the efforts made by Broward County in combining the northern and central/southern variable density models into a single merged model encompassing the urban areas within the county. The proposed model will be constructed using MODFLOW 6 (Hughes and others, 2017), which incorporates the capabilities ofMODFLOW-2005, SEAWAT, and MODFLOW-USG allowing for the simulation of variable density groundwater flow using an unstructured grid. The ability to simulate using an unstructured grid permits the use of a refined grid in areas of particular interest such as coastal well fields without the computational burden of grid refinement throughout the study area or the use olf submodeling.

The first task will be to identify, gather, and organize expanded or improved input datasets for the entire modeling domain. This includes updating observations and stress inputs such as historical groundwater levels, groundwater and surface-water salinity measurements, historical canal stages, and historical recharge/precipitation rates. Potential data sources include South Florida Water Management District, Broward County, cities and municipalities, as well as local water control and improvement districts. Improvements to state-wide estimated historical evapotranspiration (ET) have been made in recent years and will be incorporated into the model input dataset. Additionally, improved information about the surface-water canal system is now available from the ongoing inundation model project and can

provide expanded canal coverage and improved knowledge concerning the surface-water/groundwater interactions (Decker, in preparation).

The second task will be to transfer the existing and improved datasets from the merged variable density model into the MODFLOW 6 framework. This task will include the identification of areas where it would be desired to use the grid refinement capabilities of MODFLOW 6. The result from this second task will be a single, variable-density groundwater flow model ("historical model") of the urban area of Broward County capable of completing an historical simulation of approximately 50 years using the estimated model parameters from the previous studies.

The third task will involve the recalibration of the single model using the model-independent Parameter ESTimation (PEST) software. PEST was previously used for the estimation of the groundwater flow parameters for the northern and central/southern models as separate studies. The groundwater flow model parameters will be estimated using observed historical groundwater levels and salinity values. The fit to the observed salinity distribution will emphasize historical trends and the timing of the movement of the saltwater front as evidenced in the salinity observations. The newly estimated model input parameters will then be incorporated into the historical model and the simulated results from the historical period will be used as a baseline for the evaluation of the effects of the projected changes to the future hydrologic conditions.

The fourth task will be to define and simulate several future conditions scenarios to evaluate the effects on the salinity distribution and movement of the saltwater front. The scenarios should incorporate projected sea-level rise and possible changes to precipitation. Changes in pumping rate and the reallocation of pumping between well fields could also be evaluated to assess the effects on the saltwater front. At this point, additional mitigation/adaptation strategies could be identified and evaluated with input from Broward County managers.

The fifth task will be to document the model development, results, and analysis. A U.S. Geological Survey Scientific Investigations Report will be prepared and published at the conclusion of the study. Additionally, a U.S. Geological Survey data release will be prepared and will contain all the necessary executables and model input files to reproduce the historical and future scenario modeling results. The data release will also contain any pre- or post-processing executables required for simulation analysis.

Throughout the model development, testing and documentation the U.S. Geological Survey will work with officials at Broward County to facilitate the transfer of knowledge to prepare them for future modifications and scenario development. This collaboration would include the development of pre-processing tools that create new stress inputs or change model parameters and post-processing tools to examine model results. A guided workshop will be arranged near the completion of the project to further explain the model components and convey the necessary steps in reproducing the simulation results and creating new scenarios to test.

6. QA/QC and Data Management

No new hydrologic data will be collected for this project; all data being used are pre-existing, and furnished by the cooperator or relevant entities, or are served from publicly available data bases, for example, DBHYDRO, or NWIS. Data analyzed for or presented in the project deliverables, that are provided by the cooperator, and are neither proprietary nor publicly available, will be released according

to USGS Instructional Memoranda IM OSQI 2015-01 regarding scientific data management, metadata, review and approval, publication and sharing, and preservation. (http://www.usgs.gov/usgs-manual/im/IM-OSOI-2015-0 I.html; http://www.usgs.gov/datamanagement/policyreferences.php). A Data Management Plan (DMP) has been developed for the proposal and included for Center and OQA review. Deep technical reviews will be conducted around the 10%, 40% and 70% completion dates. Project personnel will work with supervisor and technical leads to identify appropriate reviewers for the internal technical reviews.

The USGS will calibrate the models it develops to generally match observed groundwater levels, surface water stages, salinity, or other derived observations. The USGS will investigate model sensitivity and articulate model limitations. The model will be documented and archived according to

1) USGS Office of Groundwater Technical Memorandum 2015.02/Office of Surface Water Technical Memorandum 2015.01/Office of Water Quality Technical Memorandum 2015.01: "Policy and guidelines for archival for surface-water, groundwater, and water-quality model applications" (available at http://water.usgs.gov/admin/memo/G W/gw2015.02.pdt).
2) USGS Office of Groundwater Technical Memorandum 206.02: "Policy for Documenting, Archiving, and Public Release of Numerical Groundwater Flow and Transport Models" (available at https://water.usgs.gov/admin/memo/GW/gw2016.02.pdt)
3) "Instructions for Documenting, Archiving, and Public Release of Numerical Groundwater Flow and Transport Models" https://water.usgs.gov/ogw/policy/gw-model/

All report(s) and/or journal article(s) authored by USGS personnel will confonn to USGS Fundamental Science Practices (http://www.usgs.gov/fsp/), which include quality assurance and quality control elements.

7. Information Products

1) U.S. Geological Survey Scientific Investigations Report documenting the variable density flow model and results
2) U.S. Geological Survey Data Release containing the variable density flow model and archive

8. References

Dausman, Alyssa, and Langevin, C.D., 2005, Movement of the Saltwater Interface in the Surficial Aquifer System in Response to Hydrologic Stresses and Water-Management Practices, Broward County, Florida: U.S. Geological Survey Scientific Investigations Report 2004-5256, 73p.

Decker, J.D. in preparation, Drainage infrastructure and Groundwater System Response to Changes in Sea-Level and Precipitation, Broward County, Florida: U.S. Geological Survey Scientific Investigations Report.

Decker, J.D., Hughes, J.D., and Swain, E.D., 2019, Potential for increased inundation in flood-prone regions of southeast Florida in response to climate and sea-level changes in Broward County,

Florida, 2060–69: U.S. Geological Survey Scientific Investigations Report 2018-5125, 106 p., accessed November 3, 2021, at https://doi.org/10.3133/sir20185125.

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Evenson, E.J., Orndorff, R.C., Blome, C.D., Bohlke, J.K., Hershberger, P.K., Langenheim, V.E., McCabe, G.J., Morlock, S.E., Reeves, H.W., Verdin, J.P., Weyers, H.S., and Wood, T.M., 2013, U.S. Geological Survey water science strategy-Observing, understanding, predicting, and delivering water science to the Nation: U.S. Geological Survey Circular 1383–G, 49 p. (Also available at https://pubs.usgs.gov/circ/1383g/circ 1383-G.pdf)

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Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group, 2020, Unified sea level rise projection southeast Florida: Southeast Florida Regional Climate Change Compact Climate Leadership Committee, 36 p., accessed November 3, 2021, at https://southeastfloridaclimatecompact.org/unitied-sea-level-rise-projections/

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9. Project Schedule:
Proposed Start Date: 4/1/2023
Proposed End Date: 3/31/2026

Task#	Brief description	FY2023		FY2024				FY2025				FY 2026	
		Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
1	Data Compilation												
2	Model Development												
3	Parameter Estimation												
4	Scenario Testing												
5	Documentation												
10/40/70 technical reviews	Internal deep technical reviews												
	Proposed Guided Workshop												

10. Primary Project Personnel

USGS
Jeremy Decker, Hydrologist
Caribbean-Florida Water Science Center
4446 Pet Ln
Lutz, FL 33559
813-498-5030, jdecker@usgs.gov

Collaborating Agency
Gregory Mount, Assistant Chief Resilience Officer, Broward County Resilient Environment Department,
115 S Andrews Ave, Room 329-L
Fort Lauderdale, Florida 33301
954-519-0356, gmount@broward.org

11. Budget Summary:

Table 1. Task 1 Costs

	Project Year 1	Project Year 2	[illegible]	[illegible]	Project [illegible]
Total Project Costs	**$170,912**	**$340,488**	**$355,938**	**$181,894**	**$1,049,232**
Cooperator Funding	$ 85,456	$170,244	$177,969	$90,947	$ 524,616
USGS cost share	$85,456	$ 170,244	$ 177,969	$ 90,947	$524,616